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CHARACTERIZATION OF FRAGMENT SPATIAL DISTRIBUTION FROM ARENA TESTING USING PHOTO ANALYSIS SOFTWARE

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1. SUMMARY

Arena testing is a widely used tool to characterize the spatial distribution of fragments upon detonation of different types of cased munitions. A semi-circular layout of 19 specially constructed capture packs was used to capture fragments created by each of two identical cased munitions. The two munitions were detonated in a vertical and horizontal orientation to obtain a more thorough understanding of fragment distribution. The naturally fragmenting munition was 4-in diameter and 30-in long with approximately 20-lb TNT equivalent explosive charge.

Numerous layers of felt paper contained in the capture packs were of significant interest for these tests as the penetration paths of the fragments would be visible as holes in the felt paper. Digital photographs were taken of each layer of felt paper in an effort to capture the spatial distribution of fragments. Adobe Photoshop Extended CS4® (Photoshop) was the primary tool used to analyze the distribution, location, and area of penetration of fragments. Using Photoshop to find the impact locations of fragments, a plug-in called Fovea Pro® was then used to calculate the number of penetrations, approximate area of penetration, and X-Y coordinates of the impact location. The use of this plug-in expedited statistical analysis of the spatial distribution of fragments since cased munitions often create hundreds or thousands of fragments upon case fracture. The process employed reduces human error and is repeatable for any test.

As a result, various images and data were constructed and collected that showed the spatial distribution of fragments from a cased munition including a panoramic image showing penetrations and their polar coordinates. Modeling predictions estimated the main fragment spray would be concentrated at 75 to 95 degrees from the nose with respect to the axis of the munition. With the panoramic image created, it was possible to calculate the percentage of fragments at any given location in the 180 degree span of the arena which helped to confirm predictions. Based upon the results of these tests, the information gathered has proven to be useful in several technology demonstrations for base hardening and protection. Having the capability to predict areas of concentrated fragment impact has enabled engineers to design structures to mitigate the effect of frag loading and its effect on the structure.

2. INTRODUCTION

The Air Force and other government entities are concerned about protection and sustainment of airbase infrastructure and operations against conventional weapons. In order to provide adequate protection for personnel and property, it is necessary to design structures that can mitigate the effects of certain weapons. In turn, the successful mitigation of weapon effects, in this case blast pressures and fragmentation, requires an understanding of how they may affect existing or newly designed structures.

Arena tests are commonly conducted tests in which munitions are placed centrally in a 360 degree arena. Typically, about one half of the arena, or 180 degrees, is lined with capture packs designed to catch fragments expelled from the munition upon detonation. From this type of test, factors like mass, velocity, and presented area of the fragments are studied in order to fully characterize the presented threat. This work is focused solely on characterizing the spatial distribution of fragments from cased munitions. In conjunction with the guidelines of the Joint Munitions Effectiveness Manual (JMEM) and using the Test and Data Reduction Procedures for Munitions, an effective method has been established for documenting and characterizing the spatial distribution of fragments from cased munitions. The ability to perform an arena test for any cased munition allows researchers to characterize the spatial distribution of fragments.

Under this effort, the characterization of the spatial distribution of fragments for horizontal and vertical orientations of the specified naturally fragmenting cased munition was accomplished. By placing the cased munition in both the horizontal and vertical orientations, the area of main beam spray and fragment distribution can be more thoroughly characterized.

Because these munitions produce large numbers of fragments in varying sizes, tracking and measuring fragment distribution is difficult. With the use of the felt paper in the arena test capture packs, an efficient way to characterize the size and spatial distribution of fragments from the cased munitions was accomplished. The rest of this report describes the arena test set up and procedures for collecting important information relating to the spatial distribution of fragments using Photoshop and an available plug-in called Fovea Pro®.

3. METHODS, ASSUMPTIONS, AND PROCEDURES

3.1. Assumptions

A few assumptions were made about the predicted outcomes of the arena testing and construction. Picatinny Arsenal provided assistance by using two computational methods—C-language arbitrary Lagrangian-Eulerian (CALE) and PAFRAG—to predict the formation of fragments, as well as fragment velocity, mass, and distribution, resulting from the detonation of this naturally fragmenting munition. Based on estimated mass and velocities of fragments, the capture packs were designed to stop all fragments from completely penetrating. In addition, not all fragments would be recovered from the test due to the munitions ability to spread fragments over a range of 360 degrees. The capture packs span only 190 degrees so the spatial distribution of fragments would only be captured within this range. The munition was placed in line with the 180 degree marks on the capture packs to ensure both the nose and tail were captured. Furthermore, it was determined that an 8 ft tall capture pack would sufficiently capture the majority of fragments from the munition based upon modeling predictions that suggested the majority of fragments would be projected approximately 90 degrees from the axis of the munition, encompassing a 25 degree area (Figure 1). In relation to the arena axis, the capture packs covered approximately a 30 degree area from the normal axis of the munition.

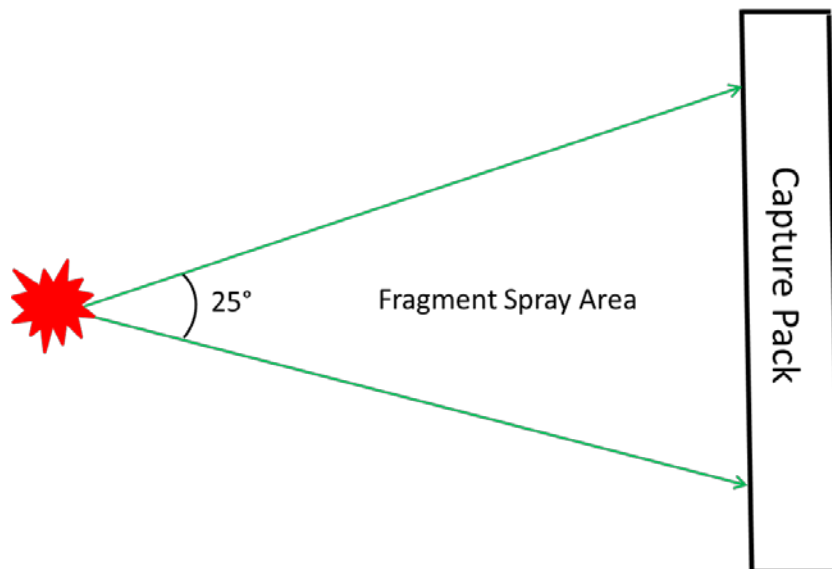


Figure 1. Predicted Fragment Spray Area

It was also expected that the post detonation processing methods of the felt paper may produce some error. Human error is reduced in computation and data processing with the method described in this paper, however, mishandling of the felt paper could have caused tears or small holes contributing to error but in general the analysis would provide valuable information. Limiting factors that could reduce any error would be related to carefully handling felt paper to reduce the risk of inadvertently creating holes in the felt paper and having high image resolution. It must also be noted when positioning the camera for taking photographs of the felt paper and

organization of felt paper samples was of high importance in order to reduce error in this process.

3.2. Procedures

3.2.1. Arena Construction

Figure 2 shows an aerial view of the arena test setup. The munition was positioned in the middle of the arena in line with the 180 degree marks on the capture packs. The vertical test orientation of the munition involved placing the longitudinal axis of the munition coincident with the blue axis shown in Figure 2. In the horizontal orientation, the long axis of the munition was placed along the green axis also shown in Figure 2.

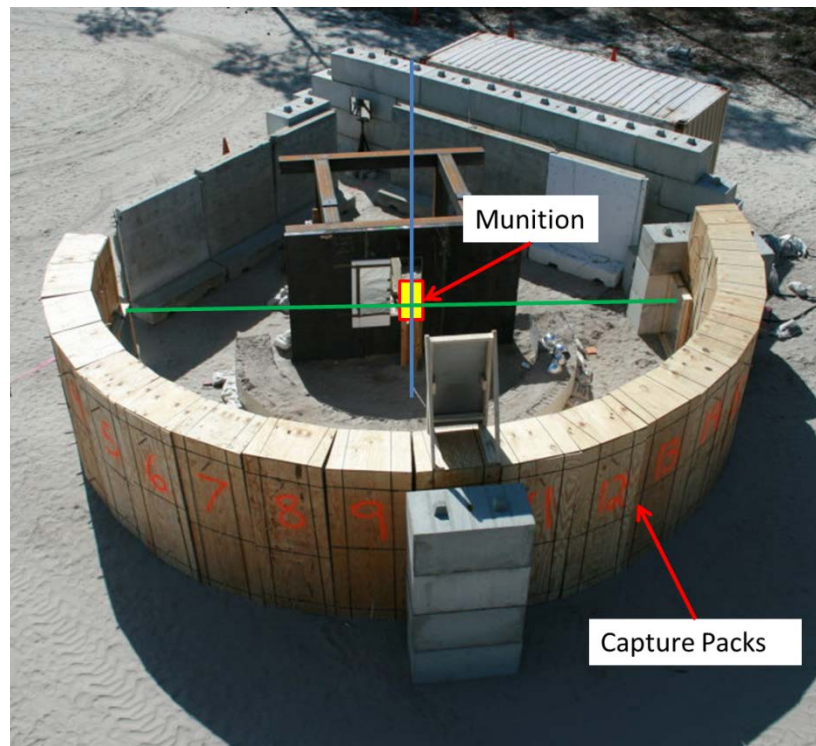


Figure 2. Overhead View of Arena Test Setup

Fully assembled the arena spanned 360 degrees with a 15-ft radius from the munition to the strike face of the capture packs, with a total 30-ft diameter. The capture packs were placed and sequentially numbered around the perimeter of the semi-circular arena, spanning a total of 190 degrees. The munition was placed centrally to the arena and 4-ft off of the ground measured from the center of the munition. The same setup was used for both the horizontal and vertical tests. Capture packs were placed and sequentially numbered around the perimeter of the semi-circular arena.

3.2.2. Capture Pack Construction

As previously stated, the JMEM was used for guidance and the Test and Data Reduction Procedures for Munitions were followed for the horizontal and vertical orientation arena tests.

For this arena test, capture packs 2.15-ft thick, approximately 3-ft wide, and 8-ft tall were constructed. The capture packs consisted of 4 pieces of $\frac{1}{2}$ in plywood. The first three sheets of plywood were backed by 16 layers of Celotex Soundstop® fiber board (Figure 3). In total, there were 48 sheets of fiber board with 15-lb black roofing felt paper placed every 4 layers of fiber board. The first layer of felt paper started behind the front layer of plywood. Each layer of fiber board from the front of the capture pack to the back was cut to length to create a 5 degree angle, creating a better interface between capture packs. This is shown in Figure 3. A total of 38 capture packs were prepared for the two individual arena tests and each capture pack was bound with plastic banding straps around the lengths and widths to prevent sliding of layers within the pack.

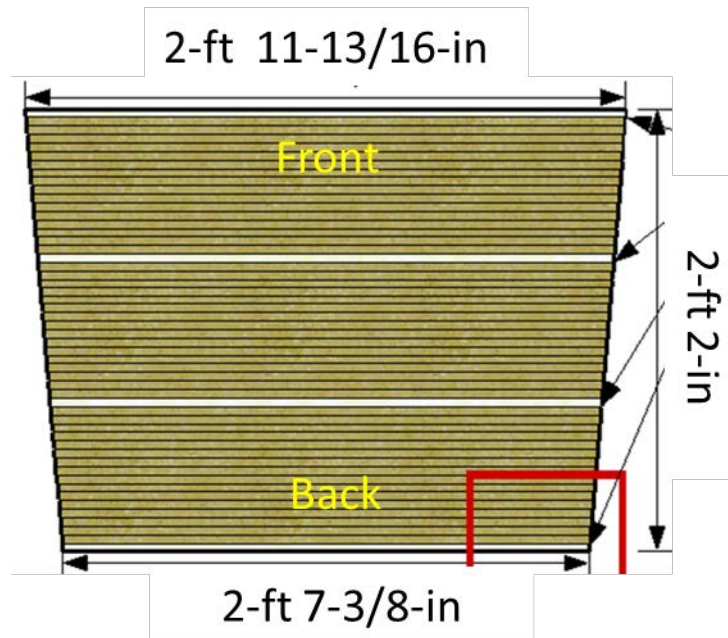


Figure 3. Capture Pack Cross Section View Showing Layers of Fiber Board

In order to set the capture packs in place, two holes were drilled through the capture packs to accommodate 1-in diameter wooden dowels. This would provide a lifting point and, in conjunction with the plastic banding straps, would also ensure that the capture packs remained aligned during transport. A high strength nylon strap was attached to the wooden dowels and front end loader with fork attachments was used to lift each capture pack and put it in place.

3.2.3. Collection of Individual Felt Paper Images

Once the arena was configured, the cased munition was detonated. Pictures were taken of the arena and the capture packs, of which each accounted for a 10 degree segment of the arena in relation to the arena axis. After taking digital images, the packs were deconstructed and as many fragment pieces that could be collected were recovered and weighed. Felt papers were removed and put into separate rolls according to capture pack. Figure 4 shows a felt paper sample post testing.



Figure 4. Felt Paper Sample Post Testing

3.2.4. Method of Analysis of Felt Paper

A light box 38.75-in wide and 103.75-in tall was constructed to back light the felt paper in order to clearly show areas perforated by fragments during the test. For sufficient lighting, four Accupro® double T5 24-in fixtures were mounted inside the light box and were spaced evenly from top to bottom with a total of 112 W of power. An initial attempt used four T8 single bulb 17-W fixtures spaced evenly within the light box. They provided an inadequate amount of light and used only half the wattage of the chosen setup. Due to the limited amount of backlighting it proved difficult to find some of the penetration holes in the felt paper when analyzing the digital images. Figure 5 shows a rough 3-D model of the constructed light box.

Commercially available light diffusers seen in Figure 6 were used to cover the front of the light box and diffuse the light to avoid over exposing any areas of the image. Construction materials used were 2×4's for the back support, 2×12's for the outside frame, and a sheet of plywood was cut to size to fit the back of the box. The four double light fixtures were installed followed by the commercial light diffusers typically used for fluorescent lighting applications. Wood screws were used to attach the 4 and ½ sheets of light diffusers needed to cover the light box. The finished light box is shown in Figure 6, showing the box lit in the dark and unlit with the lights in the room turned on.

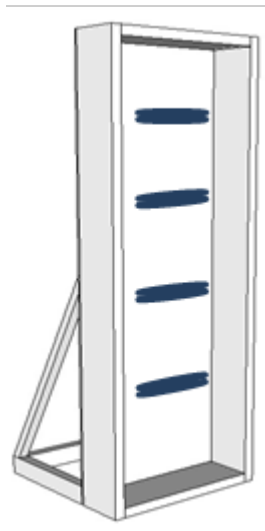


Figure 5. Light Box 3D Model Showing Basic Construction and Approximate Light Placement



Figure 6. Light Box during Operation (left); Light Box Shown in Daylight Showing 4 ½ Sheets of Commercially Available Light Diffusers (right)

Wood clothing pins were used to attach each piece of felt paper to the light box. Using a Canon Rebel XSI® digital camera with a Canon Zoom Lens (EF-S 18-55mm), images were taken of each piece of felt paper from every capture pack. The camera was positioned on a tripod with the center of the lens 58 in off the ground and 104 in from the light box. The plan and elevation views are shown in Figure 7.

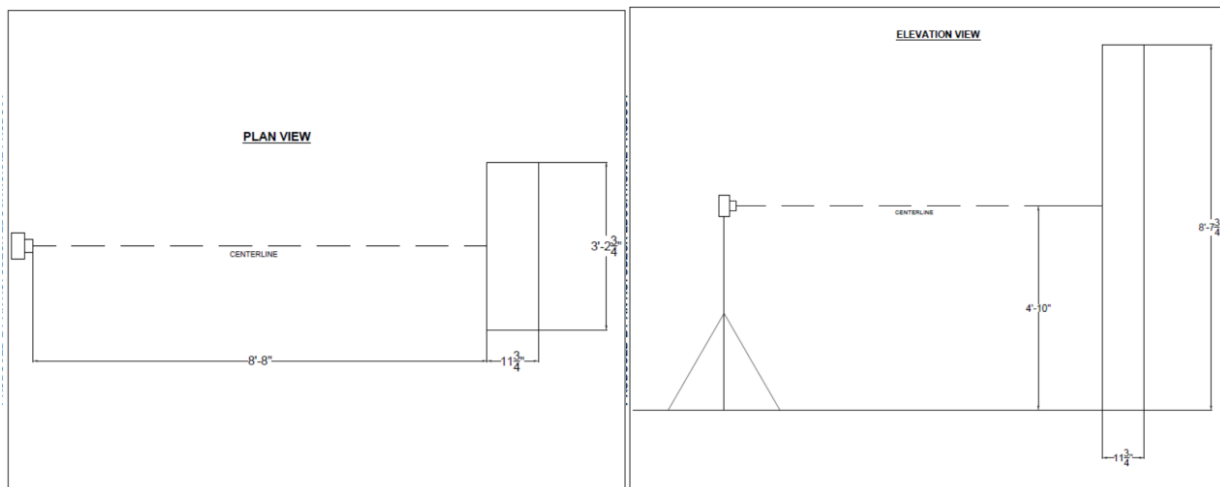


Figure 7. Plan View and Elevation View (left); Showing the Camera and Light Box Orientation Relative to Each Other (right)

Photographs were taken in a dark room in order to obtain adequate images. With the only light coming from the light box and holes in the felt paper, the cameras settings were changed to A-DEP (aperture dependent) and put on monochromatic setting (black and white). This allowed the

camera to adjust exposure time based upon the light emitted from the holes in the felt paper creating a sharper image. By changing the camera settings to monochromatic, pictures were taken in grayscale which made image analysis easier. Each image was carefully documented to ensure each layer of felt paper was accounted for and to ensure that images were properly labeled so they could be used for further analysis using Photoshop. An example of one of the images taken is shown in Figure 8.

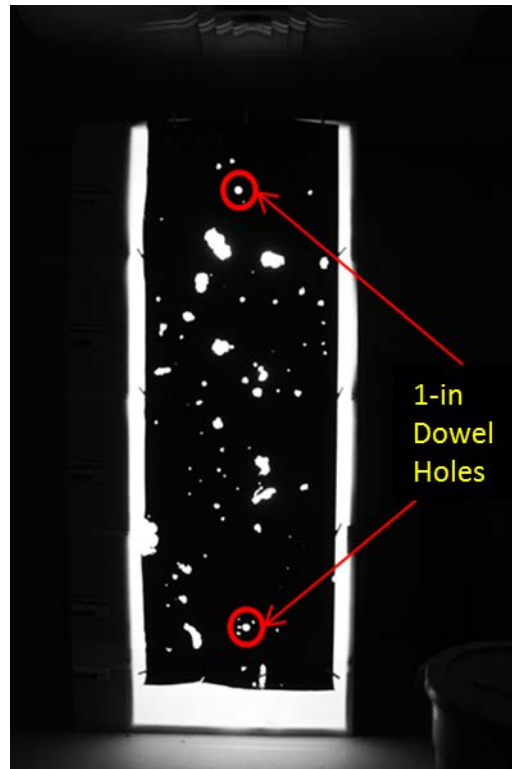


Figure 8. Unedited Photo of Felt Paper Back Lit by Light Box

3.2.5. Photoshop Procedures

Once all images were taken, as shown in Figure 8, they were imported into Photoshop. Then each image was individually cropped and the exposure offset was adjusted in order to sharpen some overexposed areas of the image. Overexposure spawned from larger holes in the felt paper that allowed more light through causing the edges of holes in the felt paper to be blurred.

Felt paper was originally aligned in capture packs using 1-in dowels. This created a 1-in hole in the top and bottom of each piece of felt paper creating a shared orientation which was used as reference marks for alignment of images (Figure 8). After processing all of the images from the capture packs, the first layer of felt paper from each capture pack in the arena was inserted into a new Photoshop file as an independent layer. By using the color selection tool the shadowed color range of each of these images was selected. This left only the felt paper selected from the image which allowed determination of where the fragments had penetrated. In summary, with monochromatic images, the dark areas can be selected and the rest of the image portions discarded leaving a digital representation of a felt paper sample.

Repeating this procedure, 19 total images were assembled in a Photoshop file containing 19 separate layers. Not all of the felt papers were exactly the same size so dowel holes were used as a point of reference to line up individual images. This created an imperfect representation of the area the capture packs covered so empty sections of the canvas in Photoshop were filled in black. This produced a uniform canvas image. The image portrayed the arena as if it had been rolled out into a flat two-dimensional (2-D) surface. This is shown in Figure 9. Another new layer was created specifically to show the boundaries between felt paper sections using red lines to distinguish between capture packs. The end result was a panoramic view of the arena and the fragment pattern left by the detonated munition. Both the vertical and horizontal tests followed the same procedure for image construction, processing, and analysis.

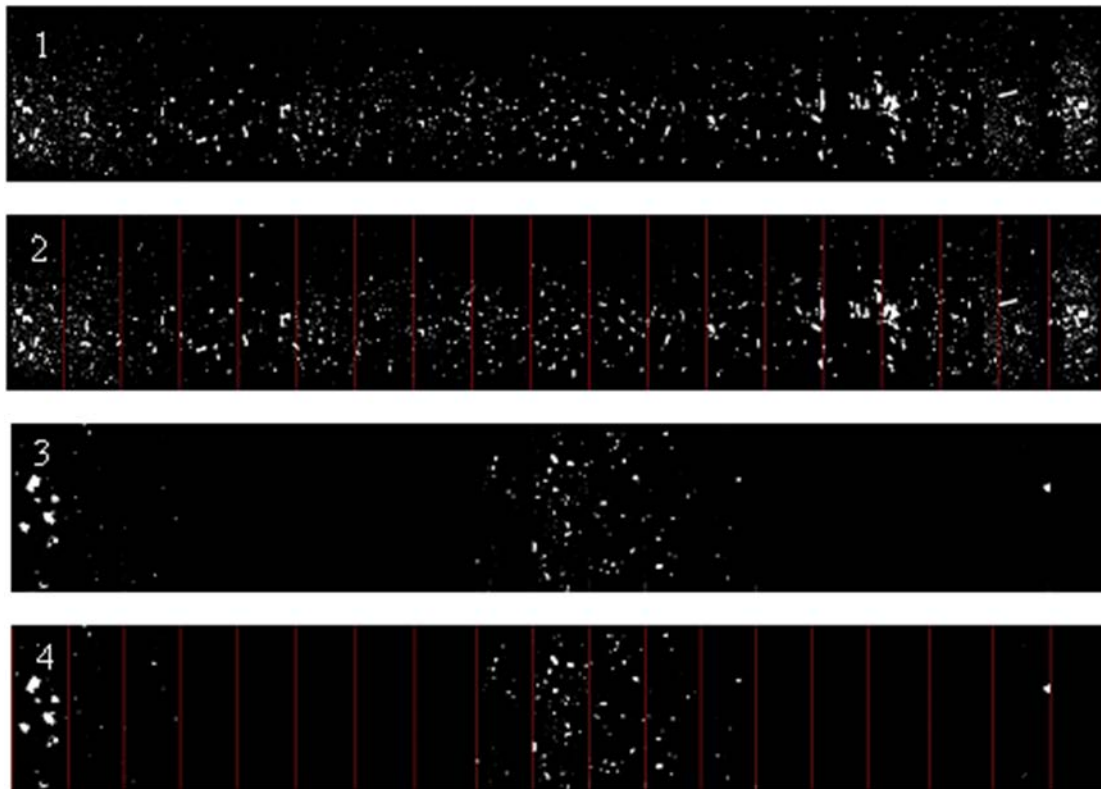


Figure 9. 1) Vertical Panorama Image; 2) Vertical Panorama Image with Red Lines Showing Felt Paper Edges; 3) Horizontal Panorama Image; 4) Horizontal Panorama Image with Red Lines Showing Felt Paper Edges

Fovea Pro® plug-in was used for statistical analysis of the fragment pattern. In order to gather information about each hole in the felt paper created by fragment impact, a special tool was used from the plug-in called IP*Measure Features. This was used to measure all features (i.e., white penetration areas). Dark areas of the image were selected using the selection by color tool. This selected all of the felt paper in the panoramic view. Then, by using inverse selection, each hole created by a fragment was selected. Basically, areas selected were all “white” areas which represented fragment impacts which were then used for the next step of analysis.

4. RESULTS AND DISCUSSION

Using the IP*Measure Features from the plug-in, a text file of the data pertaining to the location, size, and other features of each fragment impact area was created. This text file was then imported into Microsoft Excel 2007® (Excel). For the vertical test approximately 2700 features were measured while roughly 250 features were measured for the horizontal test. These features coincide with holes made in the felt paper from fragment impact. Some holes were from tears in the felt paper and roughly 38 holes were from the dowels in both images. Using Excel and the data from the Fovea® plug-in, it was possible to determine the impact locations of most of the fragments and the different angles of departure from the munition. By projecting polar coordinates onto the two dimensional image, the angle at which the fragment left the munition could be determined. This was again constructed in Photoshop using the layering function. The picture created is shown in Figure 10.

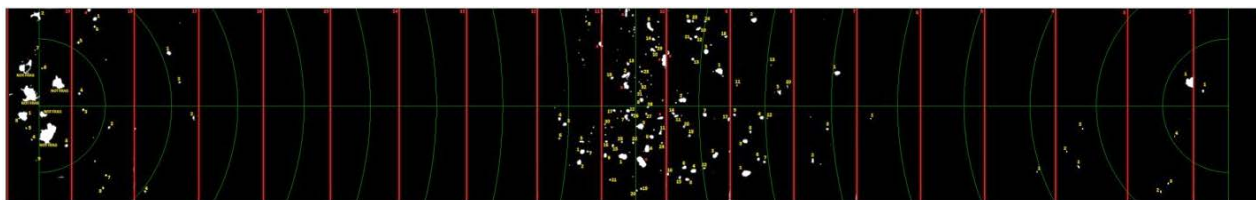


Figure 10. Panoramic View with Polar Coordinates Marked on the Image Showing the Angles at which the Target was Impacted

Figure 11 shows the percentage of fragments within a given area. This image is a 3-dimensional (3-D) projection onto a 2-D plane and polar coordinates are necessary to show the actual angles of impact. Figures 9 and 10 allow the characterization of both the impact angle and the population distribution of fragment impacts along the felt paper. Using the Fovea® plug-in, information gathered from the text file output, and the results of the examination of the data in Excel, boundaries were created to show areas where 95 percent, 75 percent, and 50 percent of the fragment impacts were located. The vertical green lines show the bounds for 95 percent, yellow for 75 percent, and magenta shows the area where 50 percent of the fragments were located.

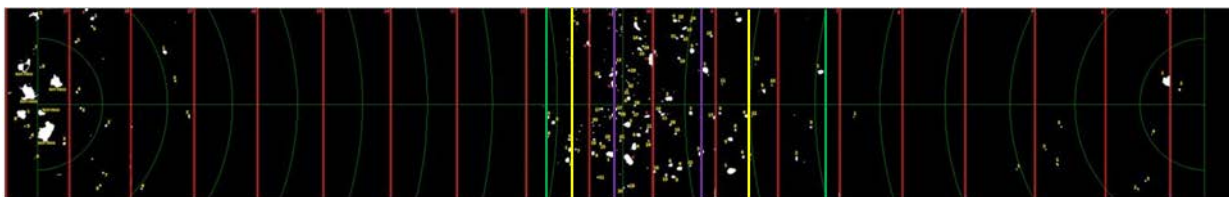


Figure 11. (Green)Boundaries Containing 95 percent, (Yellow) 75 percent, and (Magenta) 50 percent of Fragments from Horizontal Test

As a result of the construction of this panoramic image in Photoshop, a powerful visual tool was created to characterize the fragment pattern of the cased munitions tested. Photoshop was proven to be an effective tool, and a useful technique was established for producing 2-D images of a 3-D arena that are readily available for data correlation for this type of testing. With the addition of the Fovea Pro® Plug-in, statistical analysis becomes a much easier task. It allowed for the

quick/efficient/effective analysis of thousands of fragment penetrations and the recording of valuable information such as X-Y coordinates of holes and the area of the penetration. The data was readily available in just minutes. Every identified hole created by a fragment in both the horizontal and vertical tests was characterized using this plug-in allowing the ability to calculate angles at which fragments were projected from the munition and the concentrated areas of fragments from either the horizontal or vertical orientation.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

An arena test was conducted for a cased munition in both horizontal and vertical orientations to observe and document fragment spatial distribution. Capture packs containing felt paper were photographed and imported to Photoshop to create a 2-D image of the semicircular arena. The first layer of felt paper in each capture pack was used to create a panoramic image of the spatial distribution of the fragments post-detonation. In a matter of minutes after creating the image in Photoshop, thousands of fragment impacts were recorded with their coordinate of impact, presented area, centroid, and other useful data points. In particular, the vertically oriented arena test produced approximately 2700 fragment impact locations with all of the data mentioned above available within two minutes. In order to collect all of the data mentioned by hand would take weeks to accomplish the same task. This allowed the polar coordinates of fragments to be recorded as well as correlated with the fragments recovered after the arena test. The results of arena tests such as these can be applied to the development of technologies for improved hardening of infrastructure for the military against fragmenting munitions. This analysis may be useful for other types of damage assessment.

5.2. Recommendations

Testing showed that some of the capture packs required greater thickness. Some fragments penetrated the entire thickness of the packs. Slightly thicker felt paper may also be used to avoid tearing during the capture pack construction and tear down processes. Additionally, other methods for attaching the felt paper to the light box to avoid rolled tops or bottoms could be considered. Other cased munitions can be characterized using the presented method and would be appropriate for additional studies.

6. REFERENCES

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LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

2-D	two-dimensional
3-D	three-dimensional
A-DEP	aperture dependent
CALE	C-language arbitrary Lagrangian-Eulerian
Excel	Microsoft Excel 2007®
ft	foot; feet
in	inch(es)
JMEM	Joint Munitions Effectiveness Manual
lb	pound(s)
Photoshop	Adobe Photoshop Extended CS4®
W	watt(s)
TNT	Trinitrotoluene